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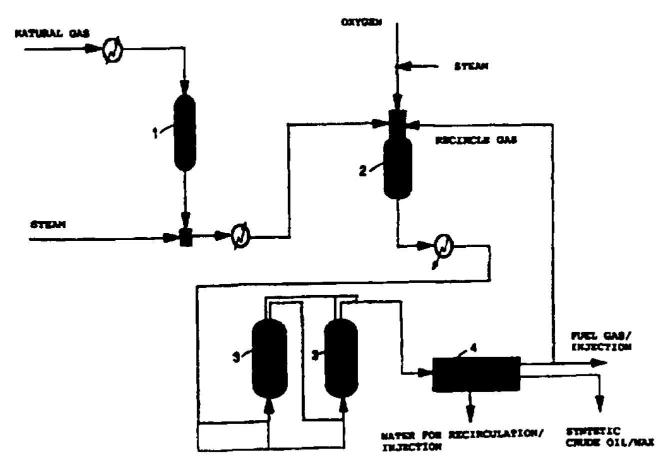

(57) Abstract

A process for treating a well stream produced from an offshore oil field, using a vessel cooperating with an underwater buoy to which both the vessel and the risers from the field are anchored. The well stream is passed to a processing plant on board, wherein water, oil and gas are separated from one another. Separated, stabilized oil is stored in storage tanks, while separated gas is passed to a conversion plant on board, for conversion of the gas to synthetic crude oil and/or wax. Also described is a plant comprising such processing plant and such conversion plant comprising at least a synthesis gas unit and a Fischer-Tropsch unit. The total plant (processing plant and conversion plant) is mounted on skids capable of being secured easily exchangeably to the deck of the vessel. Also described is a conversion plant as mentioned, wherein the Fischer-Tropsch unit comprises at least one slurry bubble column reactor (SBCR reactor) having a reactor zone arranged for containing a slurry consisting of liquid products, finely divided catalyst particles and synthesis gas, which reactor is arranged for internal separation of liquid products from the remaining part of the slurry.

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METHOD AND SYSTEM FOR THE TREATMENT OF A WELL STREAM FROM AN OFFSHORE OIL FIELD

Technical field

The present invention relates to a process and a plant for treating a well stream produced from an offshore oil field. The invention also relates to a process for converting a natural gas, especially an associated natural gas, to a synthetic crude oil via a Fischer-Tropsch synthesis, particularly a process to be carried out offshore on a vessel, a platform or other installation. The invention further relates to a plant for effecting such process, mounted on easily exchangeable skids, especially for installation on a FPSO vessel (FPSO = "Floating Production, Storage and Offloading").

Background of the invention

Production of crude oil from an offshore oil field requires a separation of the well stream into water, oil and gas. Natural gas which accompanies the produced crude oil in the well stream, and which is often termed "associated gas", must be handled in one or the other way after the separation. Often such handling consists in burning the gas, or reinjecting the gas into the oil field, but it can also be transported to the shore for further treatment. Burning has become an unacceptable method for disposing of the gas, because such burning represents a waste of progressively diminishing hydrocarbon resources and also is a source of air contamination. Reinjection, which adds costs to the crude oil production, will often be unacceptable, both due to the costs and to possible undesired effects on the crude oil production from the field. The third solution to the problem, i.e. transportation of the gas from the field, e.g. through a pipeline, for treatment in a land-based plant, will in some cases of remote fields be a costly and unpractical solution.

The conversion of a natural gas to a synthesis gas ($CO + H_2$) and conversion of the latter to a synthetic crude oil by a Fischer-Tropsch synthesis is a well known process per se, which process has been described in a comprehensive literature, see for instance G. A. Mills, "Status and future opportunities for conversion of synthesis gas to liquid fuels",

Fuel Vol. 73 (8), pp. 1243-79 (1994). In the late 80-ies, the process was subject to a renewed interest, for the purpose of treating gas transported to the shore from offshore petroleum fields, i.a. in South Africa and Malaysia. However, to the best knowledge of the present inventors, any plant based on the Fischer-Tropsch technology has not yet been installed offshore, for instance on platforms; jackups; FPSO units (FPSO = "Floating Production, Storage and Offloading") including i.a. production vessels and shuttle tankers; FSU units (FSU = "Floating Storage Unit"), semisubmersible platforms, etc.

Recently, there have become known shuttle tankers which are arranged to connect themselves to underwater loading buoys which simultaneously keep the vessel anchored. Such underwater loading buoys form a collecting point for one or more flexible risers and umbilicals from e.g. a production system at the sea bed. The buoys are adapted to be raised and secured in the topical vessel, to establish a transport system for the petroleum products from the system at the sea bed to e.g. loading tanks in the vessel.

With this technique as a starting point, there have recently been developed vessels which by simple means can change between operating as:

a) a shuttle tanker which connects itself to an underwater loading buoy,

b) a storage vessel which is permanently connected to an underwater loading buoy, and which simultaneously has unloading equipment at the stern of the vessel for unloading oil, and

c) a production vessel which is connected to an underwater loading buoy comprising a swivel means.

A vessel of this kind, which is based on cooperation between a submerged, bottom-anchored loading buoy which may comprise a swivel unit having several pipe courses, is described in NO 940352. Near to its forward end the vessel has a submerged receiving space for receiving the underwater buoy and a service shaft extending between the receiving space and the deck

of the vessel. The underwater buoy has an outer buoyancy member which is adapted for introduction and releasable securement in the submerged downwardly open receiving space in the vessel, and a central member which is rotatably mounted on the outer member and which is anchored to the sea bed and is connected to at least one transfer line extending from a respective production well up to the buoy.

When a buoy of this type is secured in the receiving space in a vessel, the vessel is rigidly attached to the outer buoyancy member of the buoy and is rotatable about the central member of the buoy which is anchored to the sea bed by a suitable anchoring system. Thus, the buoy itself constitutes a rotating body or turret about which the vessel is allowed to turn under the influence of wind, waves and water currents.

This buoy structure involves a number of substantial advantages. The central member of the buoy has a small diameter and a small mass, so that a correspondingly small diameter of the rotating body, i.e. the outer buoyancy member of the buoy, is obtained, and consequently a small rotary mass and rotational resistance. Connection and disconnection between vessel and buoy can be carried out in a simple and quick manner, even in bad weathers with relatively high waves. Further, the buoy may remain connected to the vessel in nearly all weathers, a quick disconnection being able to be carried out if a weather limitation should be exceeded.

In a vessel which is adapted for use together with the above-mentioned buoy structure, the receiving space and the shaft arranged thereabove, as mentioned, suitably are arranged in the bow portion of the vessel. This enables a relatively simple and reasonable rebuilding of existing vessels for adaptation to such a buoy loading system, for use e.g. as shuttle tankers. The combination of a submerged receiving space and a shaft which extends between the receiving space and the deck of the vessel, in addition enables a system giving a high security in operation and a low risk for contaminating spills.

For a closer description of the above-mentioned buoy structure and of a vessel of the above-mentioned type, reference may be made to the international patent applications Nos. PCT/NO92/-00054, PCT/NO92/00055 and PCT/NO92/00056.

An advantageous adaptation of such a buoy loading system for offshore oil and gas production on a production vessel is described in NO 922043. In the embodiment described therein, the system comprises a swivel unit which is arranged to be lowered to or hoisted up from an operating position at the lower end of the shaft, and to be connected in the operating position to a pipe system on the vessel. The swivel unit comprises inner and outer mutually rotatable swivel members. At the upper end of the buoy there is provided a coupling unit or connector in which the topical number of transfer lines are terminated, and this coupling unit is adapted for connection to, respectively disconnection from, a corresponding coupling unit at the underside of the swivel unit.

In an advantageous embodiment of the system, the swivel unit is placed on a lifting and lowering tool which is slidably mounted in a guide rail means extending between the upper and lower ends of the shaft. The swivel unit with its connector or coupling unit thereby may be placed in a simple manner in the correct position in a coupling space or compartment at the lower end of the shaft. As the most critical components, the swivel and coupling units will be easily accessible for maintenance or replacement. Connection to and disconnection from the transfer lines of the buoy may be carried out as a single-step operation, with automatic closing valves at both sides of the coupling units. Vertical movement of the swivel unit in connection and disconnection conveniently may be absorbed by flexible pipes which are fitted at right angles to the axis of the swivel unit.

A substantial advantage of this system is that it gives small system dimensions because of the use of the special buoy which itself constitutes a rotating body. This results in weight saving and a reduced equipment volume, something which gives

substantially reduced costs.

Such a system will require a minimal rebuilding of shuttle tankers which are adapted for the above-mentioned buoy loading system, for transition to production vessels. With such a production vessel, also seasonal operations will be able to be carried out, in addition to a continuous production from marginal fields, and also test production. The vessel may e.g. be used for test production during the summer months in a period having a possible surplus of shuttle tankers.

As a result of the fact that the wheelhouse of the vessel and its engine room are placed in the bow portion of the vessel and the service shaft up from the receiving space of the vessel is placed just behind the wheelhouse, the service shaft will be under the lee of the wheelhouse. In addition to the security this provides for the crew which is to carry out tasks in the shaft, with such an arrangement there is obtained a large deck area from the rearward part of the wheelhouse and backwards to the rearward deck area. When the vessel is to be used as a production vessel, this area will be able to be used for necessary process equipment and for equipment for well control.

Since the vessel is to be able to change between different fields of activity, it is preferable that the whole process installation is divided into smaller portable modules.

A vessel as above described will be very suitable as a carrier for a plant for conversion of associated natural gas to e.g. synthetic crude oil and/or wax. In addition, such arrangement will bring about advantages resulting from the swivel unit system also being suitable for use in conjunction with water injection, operation of water purification plants, well stimulation, etc., which allows for a high degree of flexibility in the utilization of the vessel. The system will also be suitable for use in waters fouled with drift-ice and icebergs, because it allows quick disconnection when needed, without risk of damage to the submersed buoy.

As mentioned introductorily, the present inventors are not aware of any offshore plant having been based on the Fischer-Tropsch technology. However, modular gas conversion plants or systems for conversion of associated gas or remote gas to synthetic crude oil for installation on vessels, offshore platforms and other offshore installations, have been described, see Dr. David D.J. Antia and Dr. Duncan Seddon "Exploiting New Opportunities for Cost Reduction and Addition of Value through Conversion of Offshore Gas to Crude Oil", presented on SECONS 1994 (Strategy and Economics in the North Sea), London, 28-29 November 1994.

In the above-mentioned publication, modular gas conversion plants or systems are described, which can be connected to new and existing offshore production systems. The modular plants are useful for converting natural gas to synthetic crude oil, wax or methanol. The publication focuses in particular on plants intended for use on fields producing from 5 to 50 MMCF/D (0.14 - 1.42 Mill. m^3/day) of associated gas. Two types of plants are assessed in the article:

(a) plants designed to strip value from the gas before reinjecting it into the field, and

(b) plants designed for a complete treatment of the gas by conversion thereof to more easily manageable and valuable products, to avoid burning, reinjecting or exporting the gas.

In both types of plant, the process comprises two main stages: (1) the natural gas is converted to a synthesis gas constituted by a mixture of carbon monoxide, hydrogen and carbon dioxide in a partial oxidation unit, and (2) the synthesis gas is converted to a synthetic crude oil in a Fischer-Tropsch reactor (FT reactor). The process is said to be a flexible process allowing switch-over, while in operation, to other end products ranging from light condensate to microcrystalline wax.

The equipment for the two stages of the process can be arranged in separate skid-mounted modules or groups of modules. Mounting the plant on a module basis is said to provide a flexibility reflected i.a. by the plant's capacity to be

upgraded or downgraded as required, or by the plant's capacity to be run with parallel streams producing different products, e.g. synthetic crude oil, wax and methanol.

For the production of a synthesis gas from the natural gas in the first stage of the process, several methods are dealt with in the Antia et al. publication. The more important thereof are partial oxidation, steam reforming, autothermal catalytic reforming, and combined reforming. Partial oxidation is preferred on the grounds of process efficiency, cost, product composition flexibility, plant size, product yield, logistics and economics.

For the production of synthetic crude oil and/or wax in the second stage of the process, i.e. the FT synthesis, a number of different types of reactors can be used, viz. MTFB reactors, which are multitubular fixed bed reactors (MTFB = "Multitubular Fixed Bed"), fluidized bed reactors, annular bed reactors, slurry reactors and Linde's isothermal reactor. Among these reactors, Antia et al. prefer the MTFB reactor on the grounds that it is proven, cheap, and flexible by being capable of being operated over a wide temperature range. The publication states that the slurry reactor has been extensively researched but has not been proved commercially.

The FT reactor utilizes iron, cobalt or ruthenium catalysts. All these catalyst types are said to be capable of creating products ranging in composition from light condensates to heavy paraffinic oils or microcrystalline or paraffinic waxes.

Thus, even though much of the basis has been laid for an economically justifiable and environmentally lenient handling of associated natural gas by conversion thereof to valuable and more easily manageable products, there is still a need for improved solutions to achieve a safer and more profitable operation.

Not the least, the above-mentioned MTFB reactor, considered by Antia et al. to be the preferred reactor for use in the FT

synthesis, is encumbered with drawbacks due to its high weight, a costly and complicated design and a narrow range of operating temperatures. In order to maintain the pressure drop through the catalyst bed of the MTFB reactor at an acceptable level, large catalyst particles must be used, which entails diffusional restrictions. For that reason and due to difficult temperature control in the reactor, the per pass conversion of synthesis gas is lower than would have been desirable. Furthermore, replacement of the catalyst is complicated with this type of reactor and the reactor is not suitable for highly active catalysts.

Objects of the invention

Against the above background, it is an object of the invention to provide a process and a plant for treating on board a vessel a well stream produced from an offshore oil field, using a vessel in cooperation with an underwater buoy to which both the vessel and the risers from the field are anchored.

It is a further object of the invention to provide a process for conversion of a natural gas, especially an associated natural gas, to a synthetic crude oil and/or wax, which process is suitable for being carried out in locations with a limited space, e.g. offshore on a vessel, a platform or other installation.

It is another object of the invention to provide a simple, compact and operationally reliable plant for conversion of a natural gas to a synthetic crude oil and/or wax. More particularly, it is an object to provide such plant for conversion of an associated natural gas, mounted on skids capable of being secured easily exchangeably to a vessel, an offshore platform or other offshore installation, especially a FPSO vessel (FPSO = "Floating, Production, Storage and Offloading").

A still further object is to provide a plant of the above type, which can easily be readjusted for production of products having different specifications, and which can also be

easily readjusted in respect of its production capacity.

Summary of the invention

According to a first aspect of the invention, a process is provided for treating on board a vessel a well stream produced from an offshore oil field, using a vessel cooperating with an underwater buoy to which both the vessel and the risers from the field are anchored, a swivel unit being arranged in the vessel above the buoy. The process is characterized by the steps of passing the well stream to a processing plant mounted on easily exchangeable skids secured to the deck of the vessel on either side of a pipe rack centrally located longitudinally in the vessel; separating water, oil and gas from one another in said processing plant; storing separated, stabilized oil in at least some of the vessels' storage tanks; and passing the separated gas to a plant for conversion of the gas to synthetic crude oil and/or wax, which is then stored in storage tanks in the vessel, the synthetic crude oil being optionally blended with the stabilized oil.

According to a second aspect of the invention, a plant is provided for treating a well stream produced from an offshore oil field, which plant is arranged for installation on board a vessel and comprises a processing plant in which water, oil and gas are separated from one another, The plant is characterized in that it also comprises a plant for conversion of the separated gas to synthetic crude oil and/or wax, that said conversion plant comprises at least a synthesis gas unit and a Fischer-Tropsch unit, and that the total plant (processing plant and conversion plant) is mounted on skids capable of being secured easily exchangeably to the deck of the vessel.

According to a further aspect of the invention, a process is provided - especially for being carried out offshore on a vessel, a platform or other installation - for conversion of a natural gas, especially an associated natural gas, to a synthetic crude oil and/or wax in two stages, wherein (1) the natural gas is converted to a synthesis gas consisting of a mixture of carbon monoxide, hydrogen and carbon dioxide in a

synthesis gas unit, and (2) the synthesis gas is converted to a synthetic crude oil and/or wax in a Fischer-Tropsch synthesis. The process is characterized in that the synthesis gas from stage (1) for the carrying out of a Fischer-Tropsch synthesis is introduced, in a slurry consisting of liquid products, finely divided catalyst particles and synthesis gas, into a reaction zone in a slurry bubble column reactor (SBCR reactor) wherein an internal separation of the liquid products from the remaining part of the slurry is effected.

In a preferred embodiment of this process the synthesis gas from stage (1), after cooling and separation of water, is introduced into the bottom of the reaction zone in the slurry bubble column reactor, said reaction zone being arranged to accommodate for the slurry consisting of liquid products, finely divided catalyst particles and supplied synthesis gas, and for a volume of gas above the slurry phase; liquid product is separated from the remaining part of the slurry by means of a filtration section including a housing and a filter element which together define a filtrate zone having an outlet for the product filtrate, said filter element being arranged to be in contact with the slurry in the reaction zone; fluid communication is established between the filtrate zone and the portion of the reaction zone containing the gas volume above the slurry phase; and a mean pressure differential is established across the filter element.

According to a still another aspect of the invention, a plant is provided for conversion of a natural gas, especially an associated natural gas, to a synthetic crude oil and/or wax in two stages, wherein (1) the natural gas is converted to a synthesis gas consisting of a mixture of carbon monoxide, hydrogen and carbon dioxide in a synthesis gas unit, and (2) the synthesis gas from said unit is converted to a synthetic crude oil and/or wax in a Fischer-Tropsch unit. The plant is characterized in that the Fischer-Tropsch unit comprises one or more slurry bubble column reactors (SBCR reactors) each comprising a reactor zone arranged to contain a slurry consisting of liquid products, finely divided catalyst particles

and synthesis gas; and in that the reactor(s) is/are arranged for internal separation of liquid products from the remaining part of the slurry.

In a preferred embodiment the plant is characterized in that each slurry bubble column reactor comprises: a vessel defining a reaction zone arranged to accommodate both the slurry phase and a volume of gas above the slurry phase; means for introducing the synthesis gas in the slurry phase in the lower region of the vessel; a filtration section arranged to separate liquid products from the slurry phase, including a housing which at least partially surrounds the vessel, and a filter element which together with said housing defines a filtrate zone having an outlet for the product filtrate, said filter element being arranged to be in contact with the slurry in the slurry zone; means establishing fluid communication between the filtrate zone and that part of the reaction zone which in use is to be occupied by the volume of gas above the slurry phase; and means for establishing a mean pressure differential across the filter element.

In preferred embodiments the plant is mounted on skids which can be secured easily exchangeably to a vessel, an offshore platform or other offshore installation, especially a FPSO vessel (FPSO = "Floating Production, Storage and Offloading").

<u>Brief description of the drawings</u>

Fig. 1 is a simplified flow diagram for an embodiment of the process of the invention.

Fig. 2 is a schematic section through a slurry bubble column reactor for use in the FT synthesis unit in the process of the invention.

Fig. 3 is a perspective view, partially sectioned, of a cargo and production vessel having a buoy loading system for loading of hydrocarbons, and having a space for installation of a plant for carrying out the process of the invention.

Fig. 4 is a perspective view of a production vessel having a modular plant of the invention mounted on board.

Detailed description of the invention

The main features of a preferred embodiment of a two stage process and a plant according to the invention for conversion of a natural gas, especially an associated natural gas, to a synthetic crude oil and/or wax, shall now be described with reference to the appended Fig. 1. An associated gas at a pressure of about 40 bar is heated to about 400 °C and is introduced into an absorption tower 1, wherein sulphur, which will be present in the form of H_2S only, is absorbed in a bed of ZnO particles. The desulphurized gas from the absorption tower is mixed with steam and the mixture is heated to about 500 °C and is introduced into an autothermal reformer 2. Oxygen extracted from air is mixed with steam and is introduced at about 300 °C into the autothermal reformer. A recircle gas from the FT synthesis, heated to about 300 °C, is also introduced into the reformer. The autothermal reformer comprises a burner wherein the reactants are blended, a combustion zone wherein hydrocarbons are combusted with oxygen to CO and H_2O, a thermal zone and a subsequent catalyst-filled zone wherein remaining hydrocarbons and water are converted to CO and H_2, and wherein the equilibrium between CO and H_2O on the one hand and the equilibrium between CO_2 and H_2 on the other hand, are established (the water gas shift reaction). The ratios between the reactants and other reaction conditions are ajusted to achieve a molar ratio of H_2 to CO in the range of from 1.6:1 to 2.0:1 in the outlet from the autothermal reformer 2.

The synthesis gas withdrawn from the autothermal reformer is quenched to about 300 °C by direct injection of water into the gas. The synthesis gas is cooled further in a heat exchanger and water is separated therefrom (not shown). The synthesis gas is then introduced at about 200 °C into the FT synthesis unit, which in the plant illustrated in the figure is constituted by two reactors 3. The components of the synthesis gas react with one another in an exothermal process to form

hydrocarbons and water. The FT reactors are of the slurry bubble column reactor type ("Slurry Bubble Column Reactor" = SBCR), and a catalyst on Co basis supported on an alumina carrier is employed. The term "slurry", as used herein, designates a three-phase mixture of solid catalyst particles, liquid hydrocarbons consisting of products from the FT synthesis, and gas consisting of unreacted reactants and gaseous hydrocarbons formed in the FT synthesis.

The excess heat is removed by heat exchange with water circulated through heat exchanger tubes arranged within the SBCR reactors 3. The hydrocarbons will exist both in gaseous phase and in liquid phase under the reaction conditions, which include a temperature of about 230 °C. Unreacted synthesis gas and gaseous hydrocarbon product are withdrawn from the top of the reactors 3. A filter system arranged in the upper part of the reactor separates the catalyst from the liquid products.

The gaseous products from the reactors 3 are cooled (not shown) and introduced into a separation unit 4 to separate out water and a liquid stream consisting of synthetic crude oil being the desired product. A portion of the separated water is recircled to the inlet of the reformer 2. A portion of the non-condensed gas withdrawn from the separation unit 4 is recircled to the inlet of the reformer 2, while the remaining portion of this gas can be used as a fuel gas for heating the feed to the autothermal reformer and/or can be used for power production in electrical generators or for production of fresh water from sea water. It is also possible to utilize portions of this condensed gas for injection purposes.

The two SBCR reactors 3 shown in the figure are connected in series but they may also be connected in parallel, which is suggested by punctured lines in the figure. When the reactors are connected in series, reaction water and liquid hydrocarbons (C_{5+}) may suitably be removed from the product stream downstream of the first reactor so as to improve the efficiency of the second reactor. If desired, each of the reactors 3 may be run separately.

Any catalyst suitable for use in a Fischer-Tropsch synthesis for the production of synthetic crude oil and/or wax may be used in the SBCR reactors in the plant of the invention, e.g. one of the iron, cobalt, nickel or ruthenium catalysts previously known for such use. A preferred catalyst is a cobalt-rhenium catalyst supported on an alumina carrier. The catalyst may optionally be promoted by a metal from the group of rare earth metals. By way of example, a cobalt-rhenium catalyst containing 20 wt% of Co and 1 wt% of Re on γ-Al_2O_3 may be used. Such catalyst is described in US Patent No. 4,801,573 and may be prepared by impregnation of γ-Al_2O_3 with an aqueous solution of $Co(NO_3)_2 \cdot 6H_2O$ and $HReO_4$ according to the incipient wetness method.

Using preferred FT catalysts one has achieved more than 85% per pass conversion of CO (up to 98% is attainable), a C_{5+} selectivity > 88% and a polymerization probability α according to the Anderson-Schultz-Flory distribution of 0.9-0.95.

A combination of the preferred catalysts and the described SBCR reactors give a high C_{5+} selectivity, a high per pass conversion of CO, stable activity and regenerability of the FT catalyst.

In an autothermal reforming process such as the one employed in the above described plant of the invention, a combination of partial oxidation and adiabatic steam reforming is used. The product gas exists in a chemical equilibrium at the outlet temperature of the reactor, which temperature is determined by the inlet temperature and the adiabatic temperature increase. The process is carried out in a fixed bed reactor. Autothermal reforming requires less equipment than conventional steam reforming and is a flexible process capable of producing synthesis gas of composition varying in dependency of adjustments of the operation conditions.

For producing the synthesis gas from the natural gas supplied to the plant, even other embodiments of the reforming process may be employed, such as steam reforming; combined reforming,

consisting in a steam reforming and a subsequent autothermal reforming; a combined reforming with pre-reforming; partial oxidation; and gas-heated reforming, consisting in an auto-thermal reforming and a subsequent steam reforming. Other options may be a combined autothermal reforming, or a reforming in a Kellogg reformer-heat exchange system.

The slurry bubble column reactor (SBCR)

Among three-phase system reactors in use in land-based Fischer-Tropsch plants, a mentioning shall be made of mechanically agitated slurry reactors, and loop and slurry bubble column reactors. All these employ small catalyst particles dispersed in the liquid. Therefore, for most applications, the liquid shall have to be separated from the slurry to remove liquid products or for catalyst regeneration purposes.

The operation of slurry bubble column reactors is simple, since mechanically moving parts are avoided. Therefore, and due to the low diffusional resistance and efficient heat transfer, these reactors are attractive for many industrial processes. However, the solid-liquid separation is usually performed outside the reactor in elaborate filtering and settling systems. The catalyst slurry is to be recycled to the reactor, sometimes with the use of a slurry pump. Thus, serious problems may be encountered in the continuous operation of slurry bubble column reactors.

A recent report issued by the United States Department of Energy addressed the question of catalyst/wax separation in Fischer-Tropsch slurry reactor systems. The report concludes: "Internal filters immersed in the reactor slurry, as used in some bench-scale or pilot-scale units, do not work successfully due to operational difficulties. A reactor with a section of its wall as a filter may be operable for a pilot plant but is not practicable for commercial reactors. Internal filters are subject to plugging risks, which may cause premature termination of the run, and commercial plants are not allowed to take chances.

The report states elsewhere that an internal filter within the reaction slurry has been employed in a research project. However, while a flow of filtrate was initially possible by employing a pressure differential, the filter soon became clogged and it was concluded that continuous operation would not be practical and that for a commercial-scale operation, it would be necessary to perform the solid/liquid separation outside the reactor.

However, recent development of the slurry bubble column reactor performed by the Applicants and described i.a. in international patent application PCT/NO94/00023, has shown that contrary to this teaching it is possible to provide a continuous reaction system for a Fischer-Tropsch synthesis, in which it is not necessary to perform the solid/liquid separation in an external filter unit, and in which a sufficiently high flow rate of filtrate for commercial operation can be achieved.

A slurry bubble column reactor for such continuous reaction system for a Fischer-Tropsch synthesis, which is well suited for use in the plant of the invention, is a reactor in which a liquid product is separated from a slurry phase containing finely divided catalyst in a liquid medium, said reactor comprising: a vessel defining a reaction zone arranged to accommodate the slurry phase and a volume of gas above the slurry phase; means for introducing the synthesis gas in the slurry phase in the lower region of the vessel; a filtration section arranged to separate the liquid product from the slurry phase, including a housing which at least partially surrounds the vessel, and a filter element which together with said housing defines a filtrate zone having an outlet for the product filtrate, said filter element being arranged to be in contact with the slurry in the slurry zone; means establishing fluid communication between the filtrate zone and that part of the reaction zone which in use is to be occupied by the volume of gas above the slurry phase; and means for establishing a mean pressure differential across the filter element.

It has been discovered that the communication between the filtrate zone and reaction zone which is achieved by the above-described design of the reactor prevents the build-up of solid material on the filter element. The mechanism is believed to be as follows: The turbulent motion of the slurry, as gas bubbles passed up through it, causes fluctuations or oscillations in the pressure at the filter element. The fluid communication between the reaction zone and the filtrate zone facilitates or enhances these pressure fluctuations or oscillations. Such a system is therefore relatively simple yet effective. The separation step, generally considered to be particularly problematic, is achieved without undue complication, and under proper operating conditions the filter element is self-cleaning.

Important advantages achieved with such SBCR reactor as compared to a MTFB reactor are i.a. the following:

- An improved thermal control of the exothermic FT reaction can be achieved by using effective heat exchangers integrated in the reactor. The improved thermal control allows a high productivity for both catalyst and reactor.
- The reactor is compact and simple, with few parts within the reactor. The installation costs of the reactor are 50-70% lower than those of fixed bed reactors (MTFB reactors).
- An internal separation of the catalyst from the FT product is performed, which eliminates the need for equipment for external separation of the catalyst.
- Because the catalyst is suspended in a slurry in the reactor, a continuous replacement of the catalyst is possible under operation.
- Because the reactor contains a slurry of small catalyst particles it is well suited for use of highly active catalysts.

Not less important is the high flexibility exhibited by the SBCR reactor in respect of operating temperature, product composition, productivity and operation situations.

The linear gas speed, the catalyst concentration and the temperature can be varied in an SBCR reactor without any major operation problems. Thus, both the produced amount and the per pass conversion can be varied. In a MTFB reactor, however, it is necessary to maintain very high linear gas speeds to achieve a favourable heat transfer between the fixed catalyst bed and the reactor wall. Therefore, the degree of conversion and the produced amount cannot be varied to any large extent.

The product composition (the ratio of wax to liquid) can be varied within wide limits in a SBCR reactor by changing the reactor temperature. This cannot be done in a MTFB reactor because the reaction speed (for a given catalyst) is determined by the heat balance. Primarily, therefore, the MTFB reactor can only be used in the lower temperature range, e.g. in the range of 180 to 220 °C, i.e. in a range giving a high ratio of wax to liquid. It is true that even for the SBCR reactor the reaction speed per unit of effective reactor volume is determined by the heat balance, but in this case a constant heat production can be maintained by a simultaneous change in the catalyst concentration.

A SBCR reactor will be more robust than a MTFB reactor in unforeseen operation situations such as for instance a full stop in the natural gas feed supply to the synthesis gas unit of the plant. For a SBCR reactor this will not entail major problems because the liquid phase which is present in a SBCR reactor has a very high heat capacity and therefore effectively will dampen the temperature variations and also other possible operational disturbances. A MTFB reactor therefore would have to be flushed with inert gas to avoid damages to the catalyst due to excessive temperature. When the plant is started up again, the catalyst in a SBCR reactor will simply be resuspended when the synthesis gas feeding is started, whereas a MTFB reactor will require a more comprehensive starting procedure to avoid uncontrolled temperature increases.

Fig. 2 schematically shows a suitable embodiment of a slurry bubble column reactor 11, including a reactor vessel 12 and a filtration section 13. The reactor vessel 12 includes a generally tubular section 14 and above this, an inverted cone-shaped portion 15. The tubular section 14 defines the slurry zone 20 in which a slurry of finely divided catalysts in a liquid medium of e.g. product hydrocarbon is accommodated. The cone-shaped portion 15 acts as an expansion chamber to prevent the slurry from foaming over and defines a gas space 16 above the reaction zone. The cone-shaped portion 15 may contain additional means (not shown) for breaking up or reducing foam formation.

At the bottom of the vessel 12, there is a gas inlet 17 and a gas distributor 18 through which the gas can be introduced into the slurry zone. At the top of the vessel 12, there is a gas outlet 19 from the gas space 16. A series of heat transfer tubes 21 are located within the reactor vessel extending between a common inlet 22 and a common outlet 23 for a heat exchange medium. The apparatus 11 will be controlled by a large number of transducers, controllers valves, pumps etc., one of which (a pressure or temperature sensor) is indicated by way of example at 24.

The filtration section 13 comprises an annular housing 25 which surrounds the vessel 12 just below the cone-shaped portion 15. Within the housing 25, a part of the vessel wall is composed of sintered metal and thus constitutes a filter element 26. Non-porous parts 27 of the vessel wall extend into the housing 25 at the top and bottom of the housing. The housing 25 and vessel wall effectively define a filtrate zone 28 and above it, a gas space 29.

An outlet from the filtrate zone 28 serves as a constant level device for the filtrate. A pipe 31 extends upwards from an outlet opening 32 near the bottom of the housing 25. A horizontal connection section 33 defines the level 34 of the filtrate in the filtrate zone 28 and extends downwards to an outlet valve 35. The valve 35 is opened to empty the accumu-

lated liquid product in the downward leg of the pipe. Of course, the downward leg may be replaced by a holding tank for the liquid product. The outlet pipe 31 is filled with liquid product between the opening 32 and the horizontal section 33.

A communication tube 38 connects the two gas spaces 16 and 29. The tube 38 has a valve 39. The communication tube 30 is also connected to the pipe 31 thus providing fluid communication between the gas spaces 16, 19 and the outlet pipe 31. The housing 25 also has an inlet 36 near the top with a valve 37.

In operation, gaseous reactants are introduced into the slurry of the catalyst and liquid product via the gas distributor 18, maintaining the catalyst particles in suspension. The correct temperature for reaction is maintained by the various sensors, e.g. 24, and the heat transfer system 21, 22, 23. Liquid product filters through the filter element 26 into the filtrate zone 28. This is encouraged by a pressure differential across the filter element, caused by a hydrostatic head as a result of the difference in level between the slurry and the filtrate. The level 34 of the filtrate is maintained constant by the vertical position of the horizontal section 33 of the outlet pipe 31.

The turbulent motion of the slurry helps to prevent the build-up of any filter cake and tends to avoid the filter element 26 becoming clogged with catalyst particles by causing fluctuations or oscillations in the pressure across the filter element 26 where the valve 39 is left open.

Gaseous products and any unreacted reactant gases are removed via the outlet 19. Any build-up of gas above the filtrate in the space 29 is avoided by the presence of the communication tube 38.

The filtration section 13 can be flushed, either by a suitable gas such as synthesis gas or a suitable liquid such as purified product, by opening the valve 37 and closing the valves 35 and 39. This forces flushing fluid back through the filter

element 26.

During normal operation, a portion of the catalyst would be removed and replaced either by new or regenerated catalyst. For reasons of clarity, the apparatus for this purpose has not been shown in Fig. 2 though it is to be understood that any standard system for doing so could be employed.

Preferably, the housing circumferentially surrounds the reactor vessel for at least a portion of the extent of the reactor vessel. The filter element may, as indicated in Fig. 2, be provided by a portion of the wall of the reactor vessel which is composed of a filter material. In an alternative embodiment, the filter element is located outside the vessel and the vessel is discontinuous in the region of the filter element. In another alternative, the filter element is located within the vessel and the housing is constituted by a portion of the vessel wall. Preferably, a fluid communication is between the volume of gas above the slurry phase and a volume of gas above the filtrate.

The communication between the space above the slurry in the reaction zone and the space above the filtrate in the filtrate zone prevents the build-up of pressure differentials in excess of that corresponding to the hydrostatic pressure. The communication may conveniently be via a tube extending between the top of the reaction zone and the top of the filtrate zone and being open to each. Preferably, the tube connecting the two volumes of gas is arranged to facilitate the escape of any gas accumulating in the upper portion of the filtrate zone.

Preferably, the amplitude or magnitude of the fluctuations or oscillations in the pressure differential across the filter element is about the same magnitude or greater than the mean value of the static pressure differential. Preferably the mean pressure differential across the filter element should be kept at a rather low level, typically less than 6 mbar (600 Pa). If the mean pressure differential is below a critical value (for instance 6 mbar), the filter is self-cleaning.

The pressure fluctuation value may be of the order of the pressure differential, for example from 10 to 200% of the pressure differential. The actual value of the pressure differential may be from 1 to 100 mbar, preferably 2 to 50 mbar.

The means for introducing gaseous reactants or components may comprise any suitable means such as a bubble cap plate, a plurality of nozzles, a frit plate, etc., preferably located at the bottom of the reaction vessel.

For a more detailed description of the SBCR reactor, a reference is made to international patent application No. PCT/NO94/00023, which is incorporated herein by reference. A reference is also made to international patent applications Nos. PCT/NO93/00030 and PCT/NO93/00031, and to GB A1 9317605.

Installation of the plant on a FPSO unit

The process of the invention is particularly useful in a plant located on board a socalled FPSO unit (FPSO = "Floating Production, Storage and Offloading"), which may be a vessel constructed and equipped for loading/unloading of hydrocarbons at offshore oil and gas production wells, storage of such hydrocarbons, and production, primarily conversion and upgrading of hydrocarbons produced from the wells.

In a series of patents and patent applications, the Applicants have shown and described vessels of the above described kind, here to be designated MST vessels (MST = "Multipurpose Shuttle Tanker"). A vessel of this kind is particularly suitable as a carrier for a plant for carrying out the process of the invention and will enable utilization to the highest possible extent of the flexibility and integration potential of such plant.

A vessel as mentioned above is schematically shown in a side view in Fig. 3. At the forward end of the vessel there is arranged a submerged downwardly open receiving space 40 for the receipt of an underwater buoy 41, and a service shaft 42

extends between the receiving space 40 and the deck 43 of the vessel. The arrangement is designed in such a manner that a submerged buoy for loading/unloading of hydrocarbons can be pulled up and secured in the receiving space, as more explicitly shown and described in the international patent applications PCT/NO92/00053, PCT/NO92/00054 and PCT/NO92/00055, and further such that there may be pulled up and secured a buoy which is adapted to cooperate with a swivel unit arranged at the lower end of the shaft, for use of the vessel as a production vessel, as more explicitly shown and described in EP 93913638, NO 922043 and NO 922045. Reference is here made to said applications, for a further description of the topical embodiments.

As appears, the wheelhouse 44 of the vessel is placed near to the bow 45 of the vessel, and further the engine room 46 with its diesel-electric main machinery is placed under the wheelhouse. The service shaft 42, which extends between the buoy 41 and the deck 43 of the vessel, is placed just behind the wheelhouse, so that crew which is to go down into the shaft, will be in lee behind the wheelhouse.

Above the buoy there is shown to be arranged a loading manifold/swivel 47 for connection to the buoy 41, and also a connecting pipe with an oil pipeline valve 48. Further, there are shown monitoring means 49, e.g. TV cameras, a shutter 50 for shutting-off the shaft 42 above the receiving space, and a guide means 51 for use in connection with pulling-up of the buoy. On the deck there is further shown to be arranged a pulling winch 52, a storage unit 53 and a service crane 54 for use in connection with i.a. maintenance. In the bow of the vessel there is arranged a pair of bow propellers 45.

Process equipment for the processing of oil is mounted on skids on the deck between the forward and rearward part of the vessel. The well stream which is produced on the field, and which is carried up to the vessel via the risers from the field and the underwater buoy 41, is here separated into water, oil and gas. This equipment is shown in the form of a

number of portable modules 56. Between the forward and the rearward part the vessel contains a number of cargo compartments or tanks 58. In the rearward area there is also shown to be arranged a flare boom 57.

Fig. 4 is a perspective view of a production vessel carrying a plant according to the invention for conversion of an associated natural gas to a synthetic crude oil and/or wax. The plant is installed behind a wheelhouse 65 in the bow portion of the vessel and behind any present receiving space (not shown) for receipt of an underwater loading buoy.

Reference numbers 1, 2 and 3 show the same process equipment as the corresponding reference numbers in Fig. 1, i.e. an absorption unit 1 wherein sulphur is removed from the natural gas, a synthesis gas reactor 2, consisting of an autothermal reformer, and two slurry bubble column reactors 3 for effecting the Fischer-Tropsch synthesis. A plant for recovery of hydrogen from part of the synthesis gas is indicated by 66, and an oxygen plant for extracting oxygen for feeding to the autothermal reactor is indicated by 67. The process equipment 1, 2, 3, 66 and 67 as well as other equipment directly connected to the plant (suggested in the figure without indication of any specific reference number) are installed on standardized exchangeable skid constructions 68 secured to the deck of the vessel. These skid constructions can easily be removed, to free the deck of the vessel for other use.

It is an important aspect of a preferred embodiment of the plant of the invention that the plant is fully adapted to and integrated with the technology forming the basis of the MST vessel, which vessel in a preferred embodiment will carry the plant. This implies i.a. that the design and construction of the plant is be adapted to the production vessel's framework dimensions for module installation; that it is adapted to the infrastructure of the production vessel, including e.g. a central pipe rack; and that it is adapted to the various auxiliary systems providing cooling water, steam, oxygen, etc. Also, the plant should basically be optimally adapted to the

oil production in any given case, in particular to the amount of associated gas produced and the extent of gas injection. Advantages achieved by integrating the plant with the auxiliary systems on board a production vessel are i.a. that unconverted gas from the plant may be utilized for production of electrical power in an electrical generator, or for production of fresh water from sea water. It is also advantageous that the relatively large amount of water which is separated from the product from the FT reactors, and which contains acid (e.g. acetic acid) and alcohol (e.g. methanol), would be useful for injection purposes on the field. A further advantage is the easy availability of sea water for cooling purposes.

The plant of the invention will suitably have a production capacity in the range of 420 to 21,000 bbl C_{5+}/day (53.5-2675 tons of C_{5+}/day), corresponding to a natural gas feed of 0.1 to 5.0 Mill. Sm^3/day, preferably a production capacity in the range of 2100 to 8400 bbl C_{5+}/day (267.5-1070 tons C_{5+}/day), corresponding to 0.5-2.0 Mill. Sm^3 of natural gas per day. A plant size of particular interest will correspond to a production capacity of about 4200 bbl C_{5+}/day (about 535 tons C_{5+}/day), corresponding to about 1,0 Mill. Sm^3 of natural gas per day.

The synthetic crude oil and/or wax obtained as a product from the plant can be blended with the crude oil produced from the well(s) and thus be shipped therewith. Alternatively, the product from the plant may be passed to separate product tanks for separate unloading from the production vessel and marketing/refining. This may be profitable in many cases, because the product obtained from the synthesis gas produced in the plant will usually be superior to conventional crude oil in respect of quality and properties, i.a. because it contains practically no sulphur. Thus, it can be suitable for instance as a starting material for the production of high cetane index diesel fuels and various high quality lube oil components.

It is an additional advantage of the skid-mounted plant that is can be installed on suitable land-based means for the

production of synthetic crude oil in periods where it is not used on board the production vessel.

Similar plants that are not adapted to a MST vessel may be useful on dedicated vessels, on permanent offshore installations, or in places ashore where e.g. remote gas may be of interest as a feed for the plant.

Described below as a working example is a simulated embodiment of the Fischer-Tropsch part of the process of the invention in a plant as shown in Fig. 2 and as generally described above.

Working example

By means of a mathematical simulation model for slurry bubble column reactors (SBCR reactors), developed by the Applicants and based on reaction kinetics data for the below described catalyst and acknowledged correlations for mass transfer and hydrodynamics in slurry bubble columns, data were provided for the operation of the Fischer-Tropsch part of a plant of the invention as shown in Fig. 2, comprising two SBCR reactors connected in series, with removal of condensed water and C_{5+} between the reactors, for the production of liquid hydrocarbons (C_{5+}) from a synthesis gas.

A cobalt-rhenium catalyst containing 20 wt% of Co and 1 wt% of Re supported on γ-Al_2O_3 was used in the reactors. The catalyst, described in US Patent No. 4,801,573, had been prepared by impregnation of γ-Al_2O_3 with an aqueous solution of $Co(NO_3)_2 \cdot 6H_2O$ and $HReO_4$ according to the incipient wetness method.

A synthesis gas of the composition given in Table 1 below was introduced into the first of the two serially connected reactors (Reactor 1) in an amount of about 153,000 Sm^3/h. The supplied amount of synthesis gas correlates with about 1 Mill. Sm^3/day of natural gas supplied to the reformer section of the plant plus recircled synthesis gas from SBCR Reactor 2. The composition of the synthesis gas is typical for a synthesis gas produced from a remote gas.

The operation conditions and the main data for the two Reactors 1 and 2 are given in Table 2 below.

The various mass streams to and from Reactors 1 and 2 are given in Table 3.

The total per pass conversion of CO in the two reactors was found to be 89%.

Table 1

Composition of the synthesis gas to Reactor 1

Component	Mole%
H_2	58.3
H_2O	0.3
CO	29.0
CO_2	11.6
N_2	0.5
CH_4	0.3

Table 2

Data for the slurry reactors

	Reactor 1	Reactor 2
Height (m)[1)]	10	10
Diameter (m)	5.8	3.9
Linear gas speed (m/s)[2)]	0.1	0.1
Reactor temperature (°C) [3)]	230	230
Total pressure (bar)	30	28
Catalyst concentration (wt%)	20	20
Conversion (CO) (%)	66.5	67.0
Reactor productivity (kg HC/m^3·h)	70	50
Catalyst productivity (kg HC/kg cat. ·h)	0.50	0.37
Selectivity for C_{5+} (%)[4)]	88	87

[1] Height of expanded slurry.

[2] At the inlet.

[3] Mean value.

[4] $\dfrac{\text{Moles of CO converted to } C_{5+}}{\text{Total moles of CO converted}}$

Table 3

Mass streams (tons/h)

Component	Reactor 1		Reactor 2	
	In	Out	In	Out
H_2	8.0	2.6	2.6	0.8
H_2O	0.3	23.5	-	7.7
CO	55.4	18.5	18.5	6.1
CO_2	35.0	35.6	35.6	36.0
N_2	0.9	0.9	0.9	0.9
CH_4	0.3	1.3	1.3	1.7
C_2-C_4	-	1.2	1.2	1.6
C_{5+}	-	16.3	-	5.3

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Patent claims

1. A process for treating on board a vessel a well stream produced from an offshore oil field, using a vessel cooperating with an underwater buoy to which both the vessel and the risers from the field are anchored, a swivel unit being arranged in the vessel above the buoy, **characterized** by the steps of passing the well stream to a processing plant mounted on easily exchangeable skids secured to the deck of the vessel on either side of a pipe rack centrally located longitudinally of the vessel; separating water, oil and gas from one another in said processing plant; storing separated, stabilized oil in at least some of the vessels' storage tanks; and passing the separated gas to a plant for conversion of the gas to synthetic crude oil and/or wax, which is then stored in storage tanks in the vessel, the synthetic crude oil being optionally blended with the stabilized oil.

2. A plant for treating a well stream produced from an offshore oil field, which plant is arranged for installation on board a vessel and comprises a processing plant in which water, oil and gas are separated from one another, **characterized** in that it also comprises a plant for conversion of the separated gas to synthetic crude oil and/or wax; that said conversion plant comprises at least a synthesis gas unit and a Fischer-Tropsch unit; and that the total plant (processing plant and conversion plant) is mounted on skids capable of being secured easily exchangeably to the deck of the vessel.

3. A process - especially for being carried out offshore on a vessel, a platform or other installation - for conversion of a natural gas, especially an associated natural gas, to a synthetic crude oil and/or wax in two stages, wherein (1) the natural gas is converted to a synthesis gas consisting of a mixture of carbon monoxide, hydrogen and carbon dioxide in a synthesis gas unit, and (2) the synthesis gas is converted to a synthetic crude oil and/or wax in a Fischer-Tropsch synthesis, **characterized** in that the synthesis gas from stage (1)

for the carrying out of a Fischer-Tropsch synthesis is introduced, in a slurry consisting of liquid products, finely divided catalyst particles and synthesis gas, into a reaction zone in a slurry bubble column reactor (SBCR reactor) wherein an internal separation of the liquid products from the remaining part of the slurry is effected.

4. A process according to claim 3, **characterized** in that the synthesis gas from stage (1), after cooling and separation of water, is introduced into the bottom of the reaction zone in the slurry bubble column reactor, said reaction zone being arranged to accommodate for the slurry consisting of liquid products, finely divided catalyst particles and supplied synthesis gas, and to accomodate for a volume of gas above the slurry phase; that liquid product is separated from the remaining part of the slurry by means of a filtration section including a housing and a filter element which together define a filtrate zone having an outlet for the product filtrate, said filter element being arranged to be in contact with the slurry in the reaction zone; that fluid communication is established between the filtrate zone and the portion of the reaction zone containing the gas volume above the slurry phase; and that a mean pressure differential is established across the filter element.

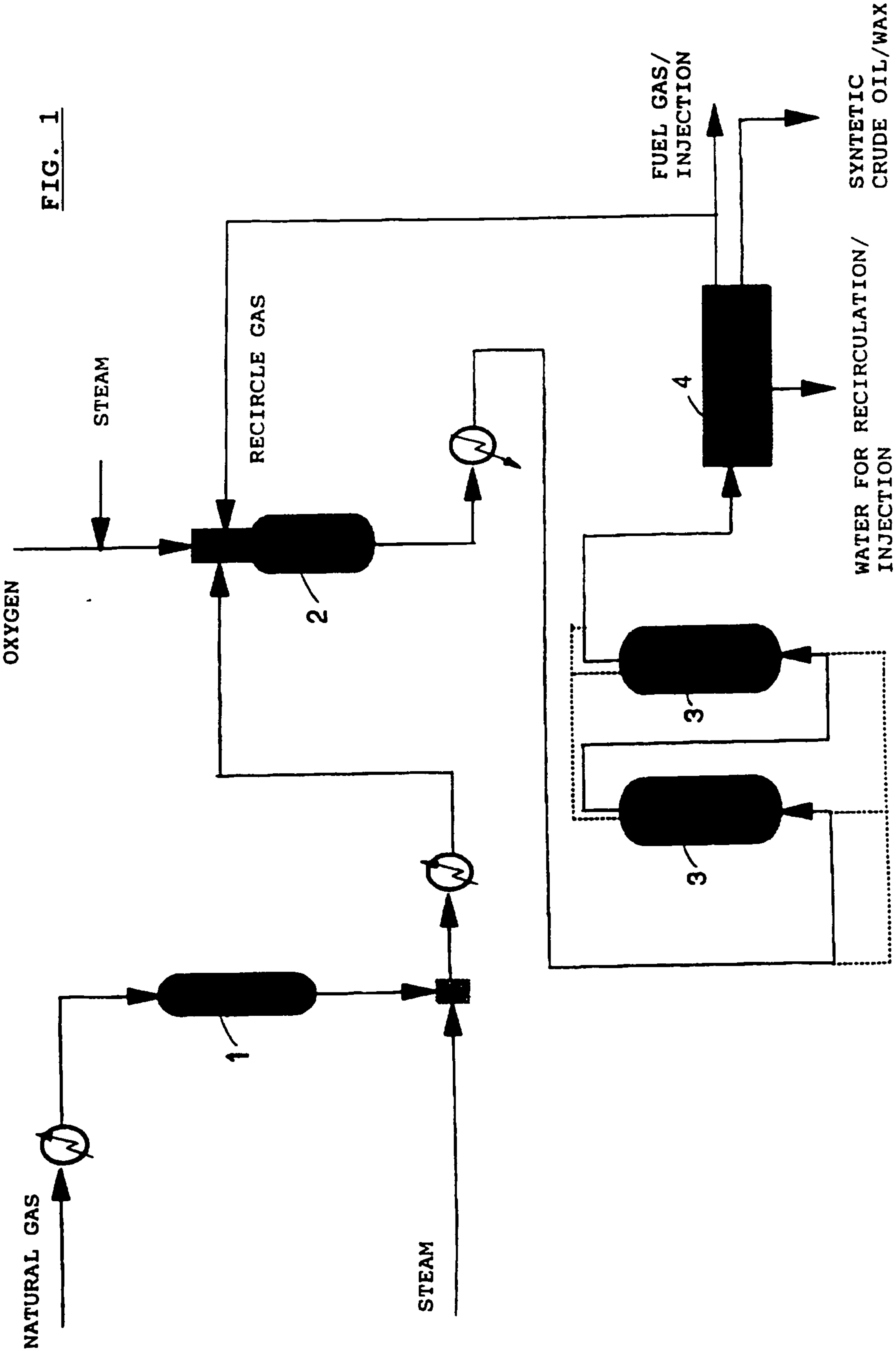
5. A plant for conversion of a natural gas, especially an associated natural gas, to a synthetic crude oil and/or wax in two stages, wherein (1) the natural gas is converted to a synthesis gas consisting of a mixture of carbon monoxide, hydrogen and carbon dioxide in a synthesis gas unit, and (2) the synthesis gas from said unit is converted to a synthetic crude oil and/or wax in a Fischer-Tropsch unit, **characterized** in that the Fischer-Tropsch unit comprises one or more slurry bubble column reactors (SBCR reactors) each comprising a reactor zone arranged to contain a slurry consisting of liquid products, finely divided catalyst particles and synthesis gas, and in that the reactor(s) is/are arranged for internal separation of liquid products from the remaining part of the slurry.

6. A plant according to claim 5, **characterized** in that each slurry bubble column reactor comprises: a vessel defining a reaction zone arranged to accommodate both the slurry phase and a volume of gas above the slurry phase; means for introducing the synthesis gas in the slurry phase in the lower region of the vessel; a filtration section arranged to separate liquid products from the slurry phase, including a housing which at least partially surrounds the vessel, and a filter element which together with said housing defines a filtrate zone having an outlet for the product filtrate, said filter element being arranged to be in contact with the slurry in the slurry zone; means establishing fluid communication between the filtrate zone and that part of the reaction zone which in use is to be occupied by the volume of gas above the slurry phase; and means for establishing a mean pressure differential across the filter element.

7. A plant according to claim 6, **characterized** in that it is located on skids which can be secured easily exchangeably to a vessel, an offshore platform or other offshore installation.

8. A plant according to claim 7, **characterized** in that it is adapted for installation on a FPSO vessel (FPSO = "Floating Production, Storage and Offloading").

FIG. 1


NATURAL GAS
STEAM
OXYGEN
STEAM
RECIRCLE GAS
FUEL GAS/
INJECTION
SYNTETIC
CRUDE OIL/WAX
WATER FOR RECIRCULATION/
INJECTION
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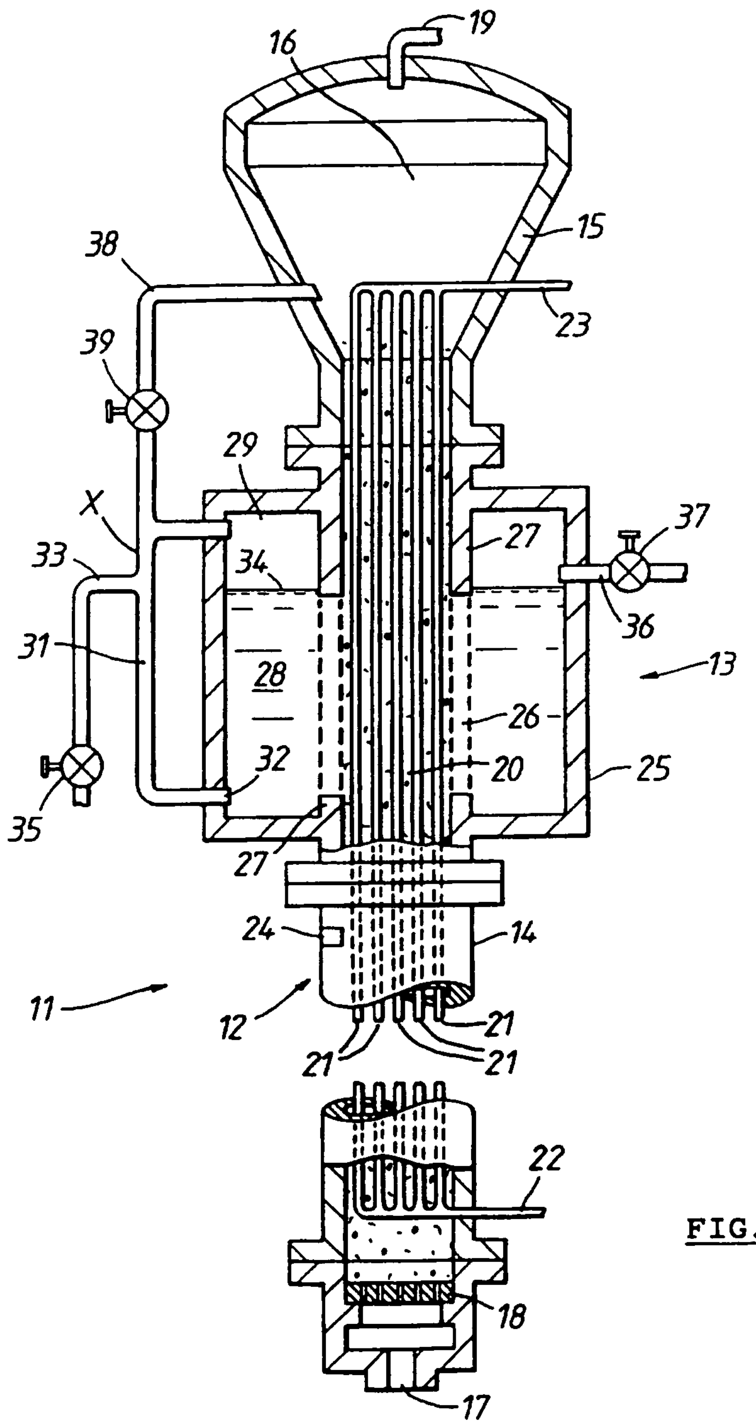
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FIG. 2

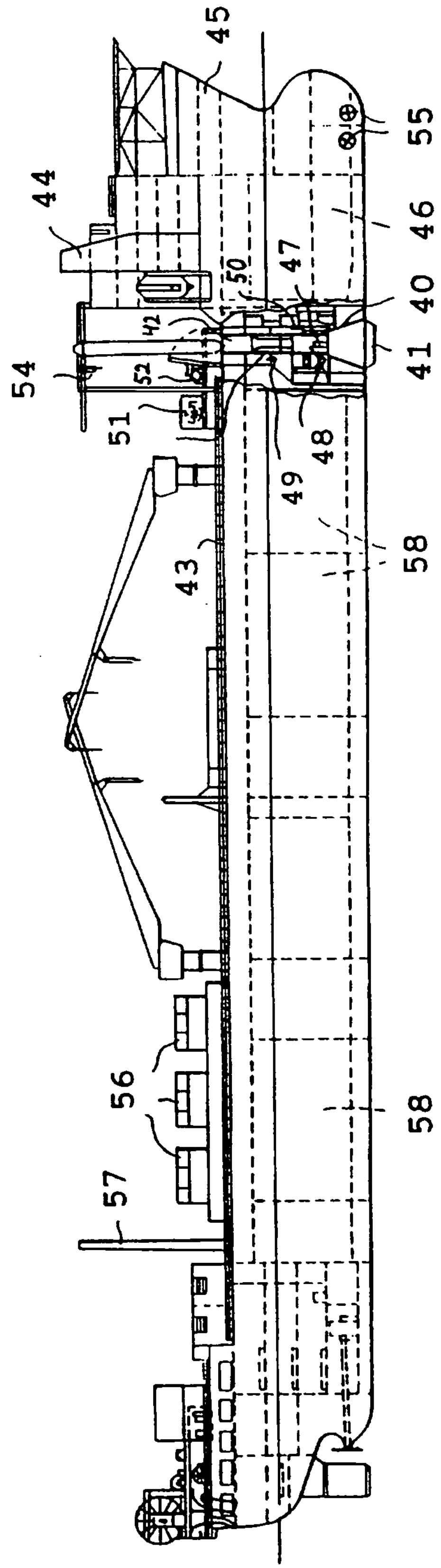

FIG. 3

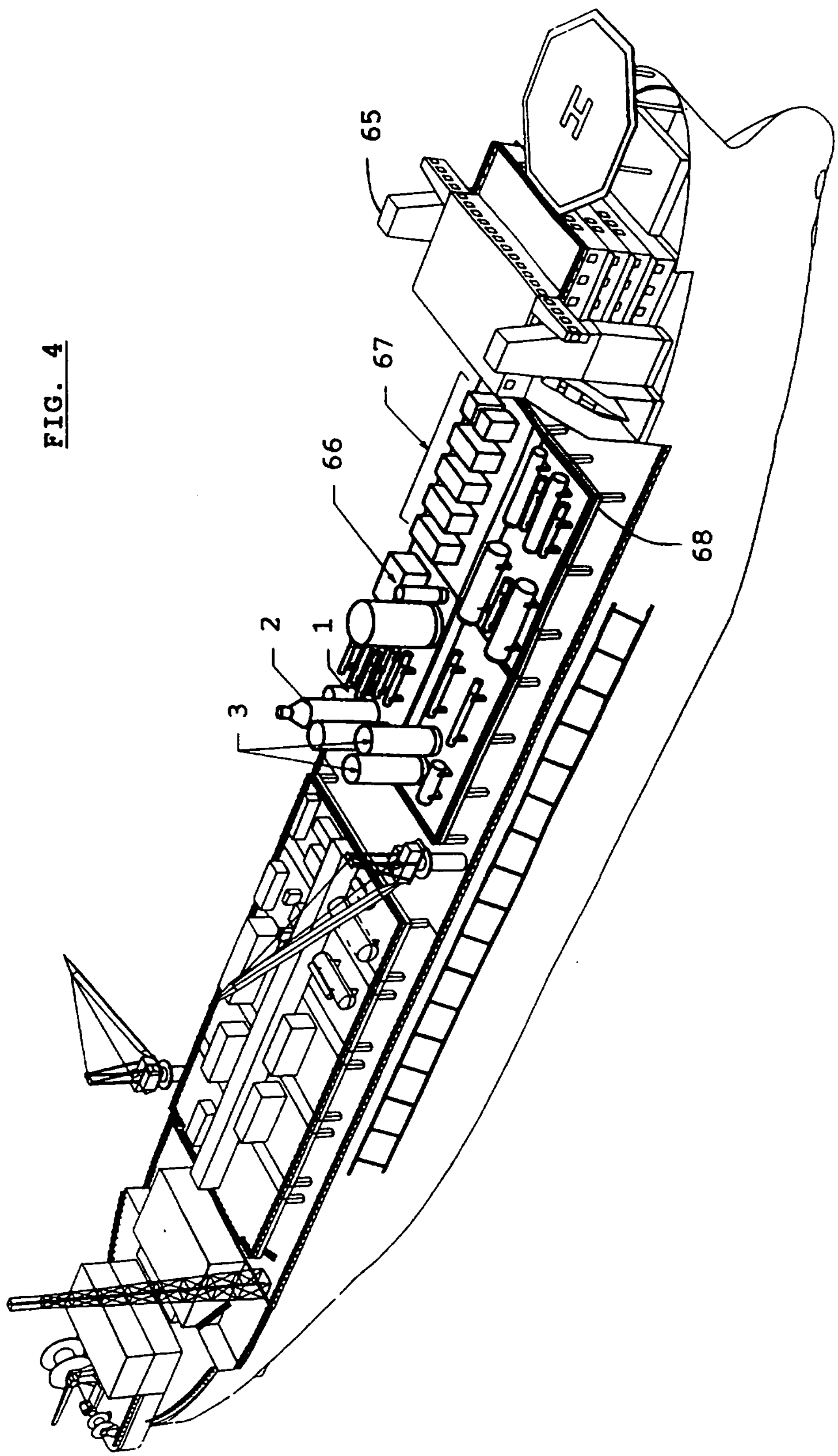

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 96/00227

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: E21B 43/01, B63B 35/44
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: E21B, B63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 9400333 A1 (KVAERNER A.S ET AL), 6 January 1994 (06.01.94), page 44, last paragraph - page 5 --	1-8
Y	US 4762858 A (D.A. HUCUL ET AL), 9 August 1988 (09.08.88) --	1-8
A	GB 1475813 A (TAPIOLA A.G.), 10 June 1977 (10.06.77) --	1-8
A	GB 1486572 A (KHD PRITCHARD GMBH GESELLSCHAFT FUR PLANUNG UND BAU PROZESSANLAGEN), 21 Sept 1977 (21.09.77) --	1-8

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 January 1997	16 -01- 1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Christer Bäcknert Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 96/00227

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4375835 A (M. ARCHER), 8 March 1983 (08.03.83) --	1-8
A	US 4520215 A (H. OWEN ET AL), 28 May 1985 (28.05.85) --	1-8
A	US 4684756 A (W.R. DERR, JR. ET AL), 4 August 1987 (04.08.87) -- --------	1-8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 96/00227

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see extra sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

One invention according to claims 1-2 relating to a method and a system for treatment, on board a ship, of a well stream and further processing of the separated gas into synthetic oil.

One further invention according to claims 3-4 relating to a method for processing a natural gas into synthetic oil in two steps.

Yet another invention according to claims 5-8 relating to a system for processing of a natural gas into synthetic oil using a certain type of reactor.

The three inventions are not considered to have such a technical relationship as referred to in PCT Rule 13.2. Consequently, unity of invention is lacking.

INTERNATIONAL SEARCH REPORT

Information on patent family members

28/10/96

International application No.
PCT/NO 96/00227

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO-A1-	9400333	06/01/94	CA-A-	2139225	06/01/94
			EP-A,B-	0648174	19/04/95
			JP-T-	7508242	14/09/95
			NO-B,C-	178725	12/02/96
			NO-A-	922562	30/12/93
			US-A-	5505151	09/04/96
US-A-	4762858	09/08/88	NONE		
GB-A-	1475813	10/06/77	AU-A-	7993275	14/10/76
			BE-A-	827755	31/07/75
			DE-A-	2515169	30/10/75
			JP-A-	51010802	28/01/76
			NL-A-	7504222	13/10/75
			SE-A-	7504079	10/10/75
GB-A-	1486572	21/09/77	BE-A-	820681	03/02/75
			DE-A-	2349879	10/04/75
			FR-A,B-	2246442	02/05/75
			JP-A-	50116301	11/09/75
			NL-A-	7413030	08/04/75
			SE-A-	7412426	07/04/75
US-A-	4375835	08/03/83	GB-A,B-	2066758	15/07/81
US-A-	4520215	28/05/85	DE-A-	3513465	24/10/85
US-A-	4684756	04/08/87	NONE		